Study of Feynman Scaling in Very Forward Neutron and Photon Production in DIS at HERA

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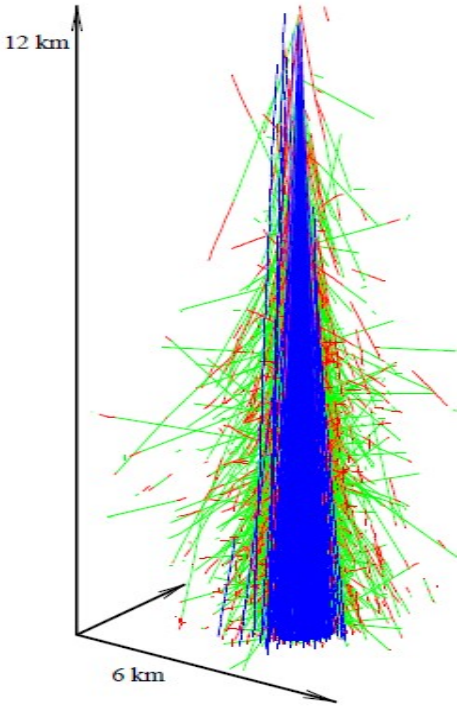
On behalf of the H1 Collaboration

Outline

- **Introduction**
- **Data selection and MC models**
- **Results**
- **Conclusions**

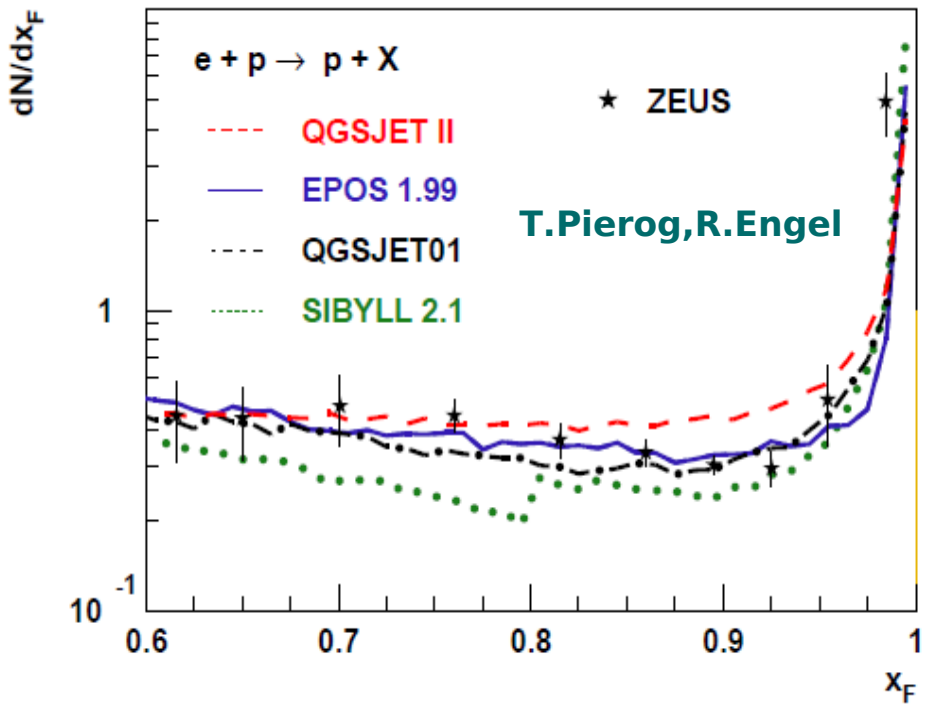
Introduction

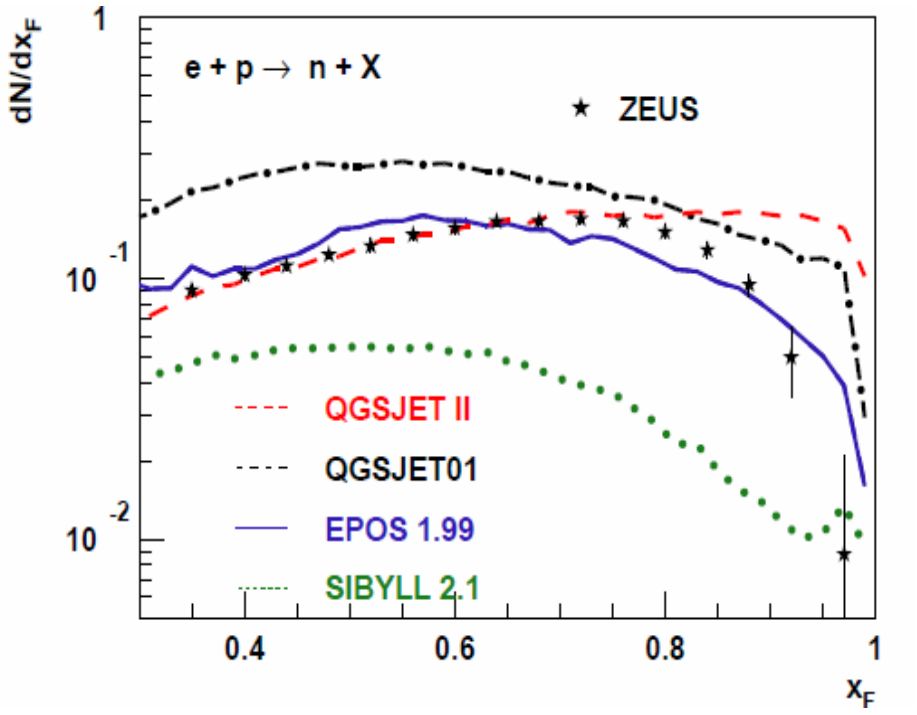
Measurements of Forward Particles (small angles to the proton beam in e-p collisions in e-p collider) are important for:



- understanding of proton fragmentation mechanisms.
- model tuning, in particular for hadron interaction in Cosmic Ray(CR) models. (The shower in matter is dominated by soft, forward interactions)
- testing the hypothesis of limiting fragmentation: the production of forward particles is independent of the energy of incident particle.
- testing of Feynman Scaling: Cross Section vs. $x_F = p^*_{||}/p^*_{||max}$ integrated over p_t is independent of CM-energy.

Comparison of leading baryons with CR models.

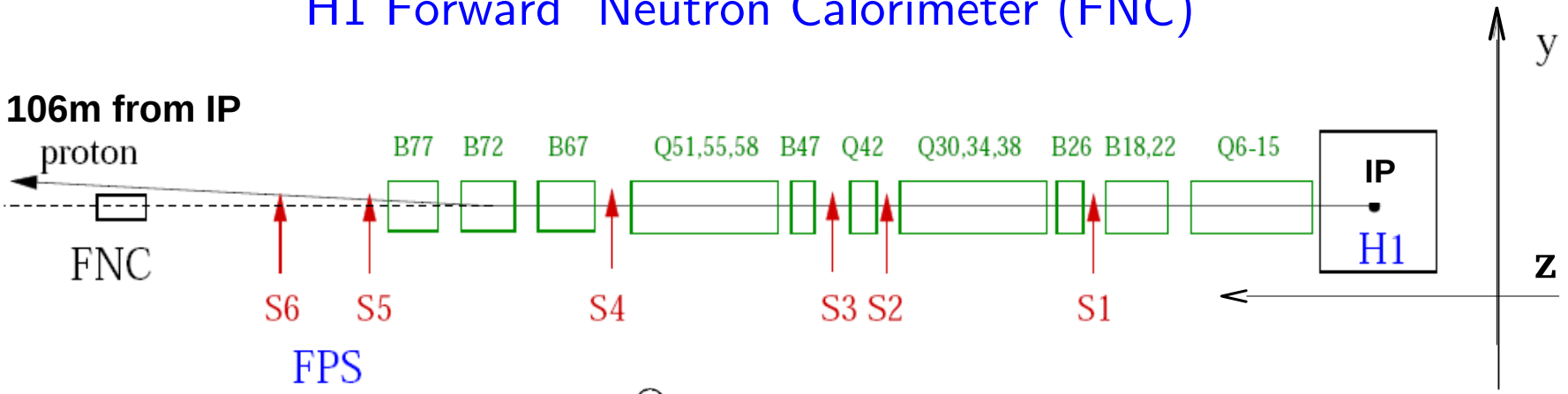


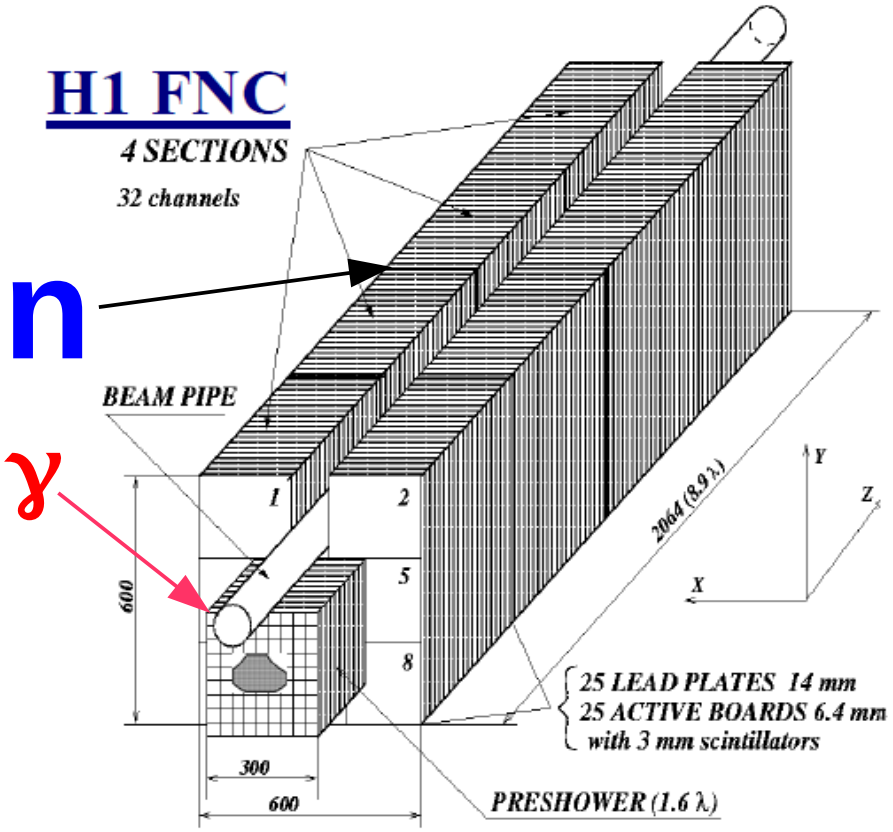


- **Reasonable prediction for leading proton data.**
- **Large difference between models for leading neutrons.**

Goal:
Measure forward photon and neutron production in DIS, make detailed comparison with models.

H1 Forward Neutron Calorimeter (FNC)





Main Calorimeter:
4 modules 60 x 60 x 51 cm^3,8.9λ

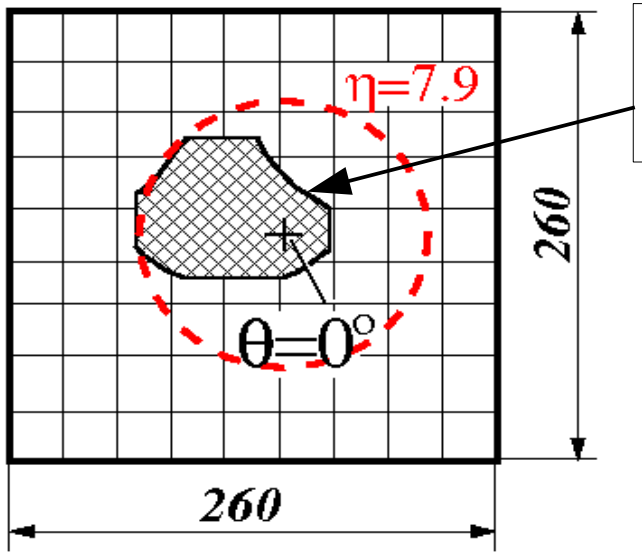
Preshower:
26 x 26 x 40cm^3, 60X_0 , 1.6λ
e/m shower contained in Preshower
⇒ separation photons from neutrons
9x, 9y strips
Position resolution:2mm
σ(E)/E≈20%/√E[GeV] ⊕ 2% for e/m shower

Identification of forward Photons and Neutrons

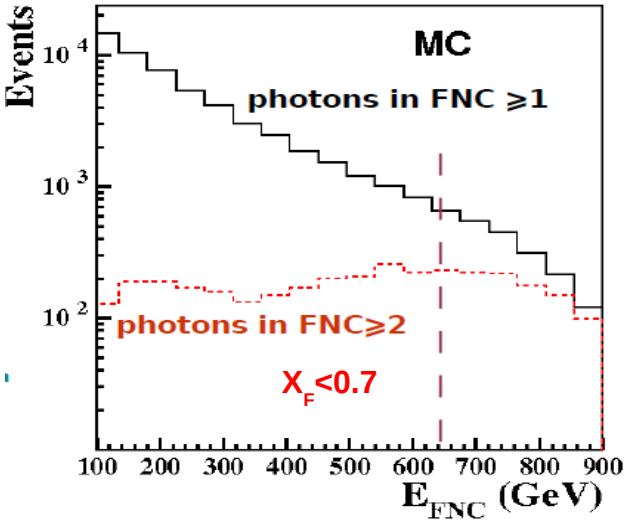
Photons: shower fully contained in the Preshower calorimeter.

Angular Restriction: Θ<0.75 mrad (η>7.9)

0.1<X_F<0.7: due to non negligible ≥2 photons

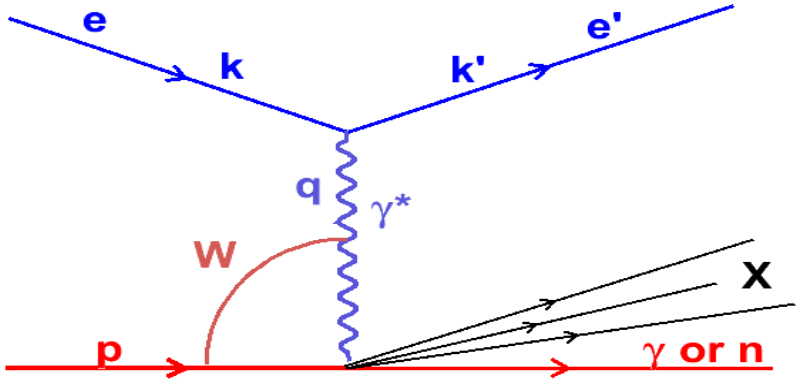


Limitating aperture from beam line elements

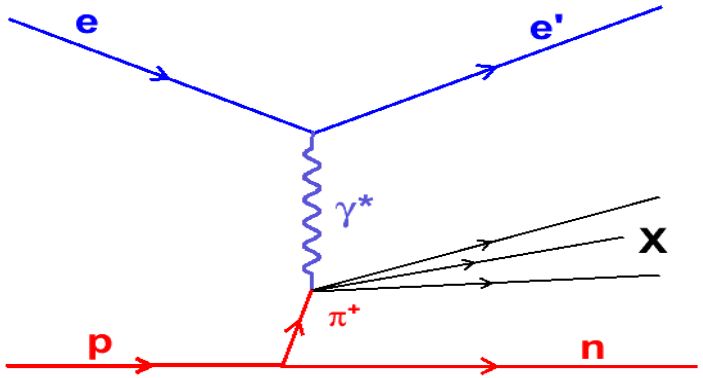


Neutrons: Contained in the Main Calorimeter (and Preshower).

Kinematics and selection cuts



γ or n production in proton fragmentation



n production via π^+ - exchange

$q = k-k'$; $Q^2 = -q^2$; $y = (qp)/(kp)$; $W^2=(q+p)^2$;

$X_F=p^*_{||} / p^*_{||max}=2p^*_{||} / W$; $X_L=E_{n\gamma} / E_p$; For Forward particles $X_F \approx X_L$

2006-2007 data;
Ee=27.5 GeV; Ep=920 GeV; $\sqrt{s}$=319 GeV
Integrated Luminosity = 126pb^{-1}

DIS selection:

$6 < Q^2 < 100$ GeV^2 $0.05 < y < 0.6$

Photon and Neutrons selection in FNC:

η>7.9 (lab frame) ;

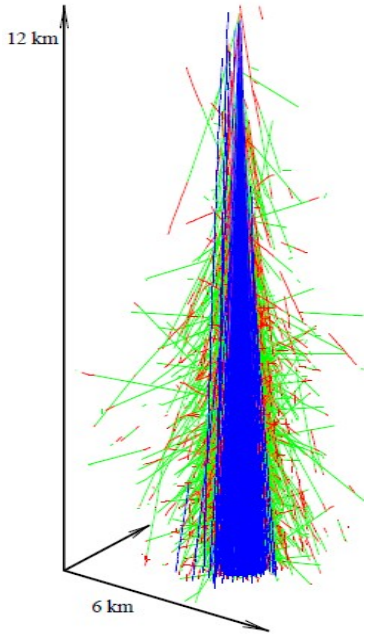
Statistics with DIS electrons:

Photons: ~ 79000 $0.1 < x_F < 0.7$

Neutrons: ~231000 $0.1 < x_F < 0.94$

Monte Carlo models

Data are compared with Monte Carlo models:



- inclusive DIS MC DJANGOH14 and RAPGAP-π:
  - LEPTO - LO matrix elements+leading log parton shower
  - ARIADNE - LO matrix elements+color dipole model (CDM)
  - RAPGAP-π - Pion exchange model

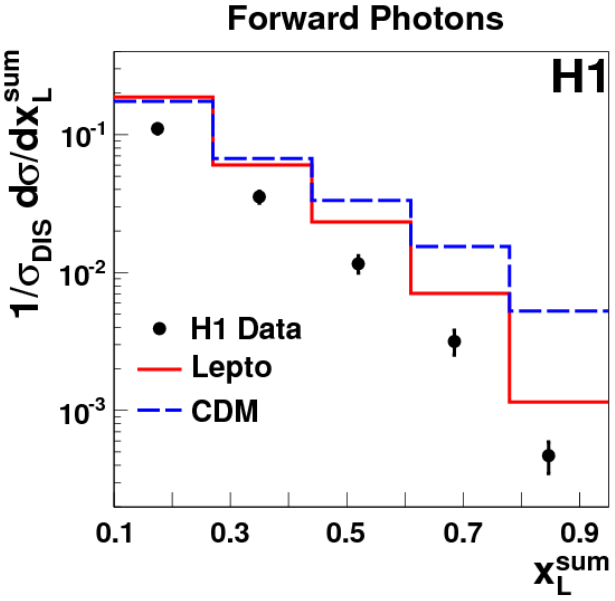
- Hadronic interaction Cosmic Rays (CR) models:
  - QGSJET 01,QGSJET II-03: (Kalmykov, Ostapchenko)
  - EPOS 1.9: (Pierog, Werner)
  - SIBYLL 2.1: (Engel, Fletcher, Gaisser, Lipari, Stanev)

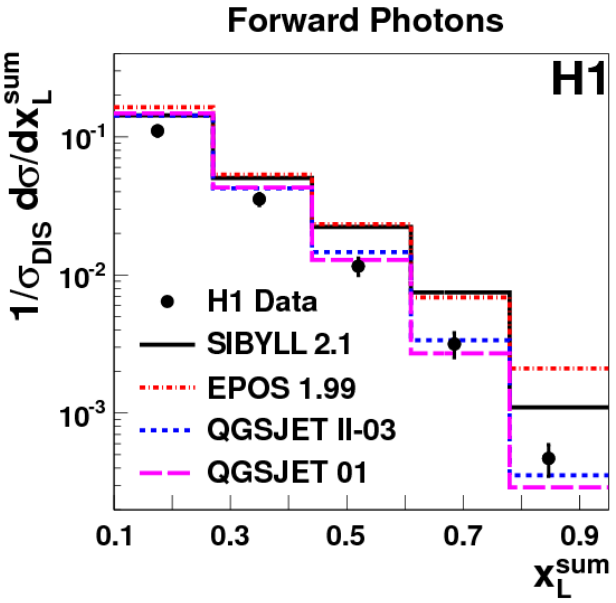
Based on:
Regge theory, Gribov-Regge approximation, perturbative QCD, unitarisation.

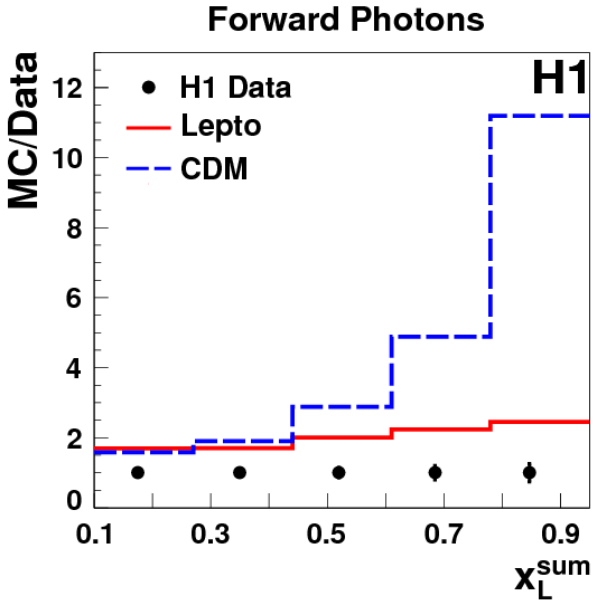
Differences in modeling ==> mini-jet production, formation of color strings and fragmentation, treatment of saturation effects, multiparton interaction, treatment of hadron remnants.

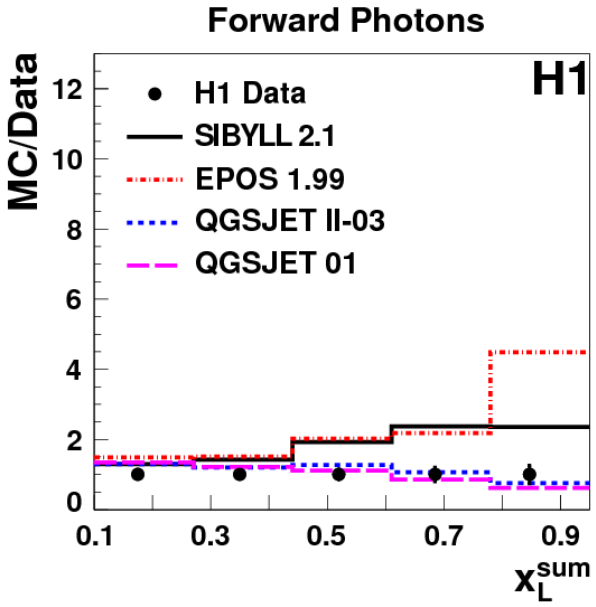
- Forward Photons are produced in π^0 decay from hadronisation of the proton remnant.
- Forward Neutrons are produced in proton fragmentation and by the **π-**exchange mechanisms, **p->n+π^+**

Normalized Forward photon cross sections vs x_L^{sum}









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Photon rate in all used MC models is significantly higher than in the data.

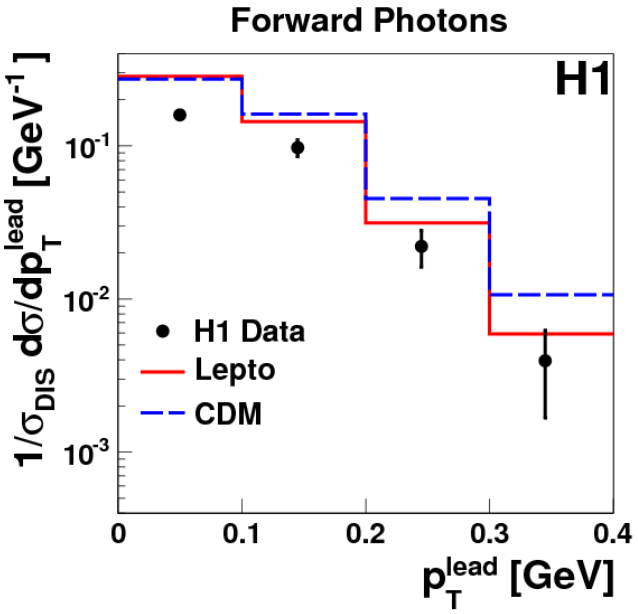
LEPTO,CDM higher by 70% CR models higher by 30-50%.

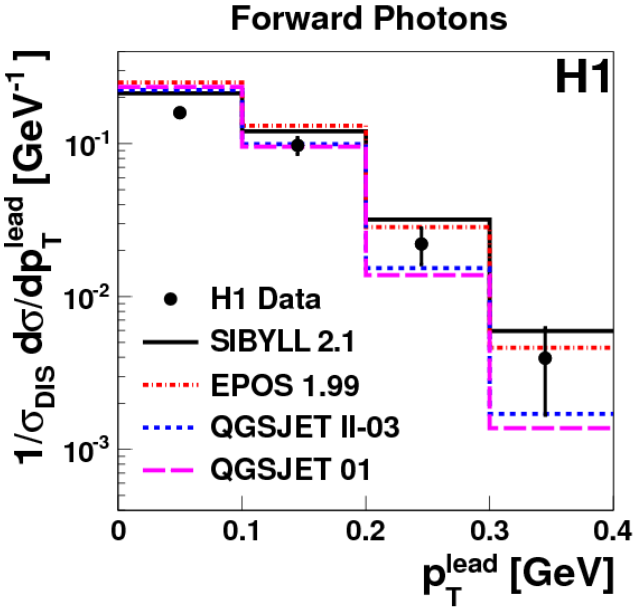
LEPTO model describe the shape reasonably well.

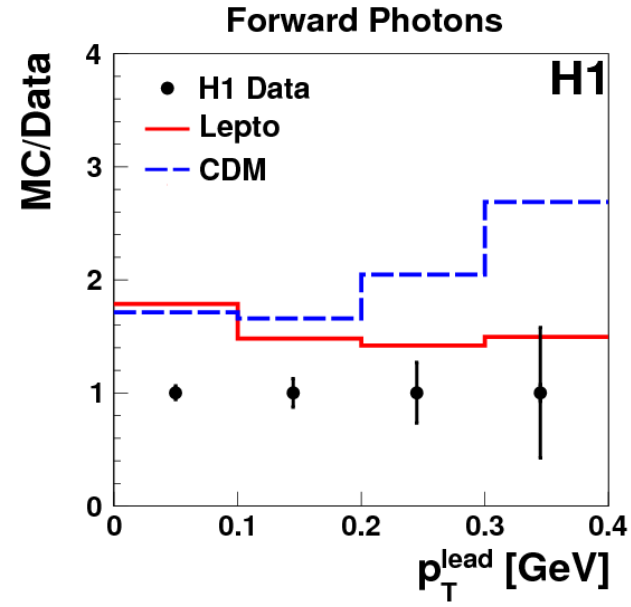
CDM to data discrepancy larger at higher x_L.

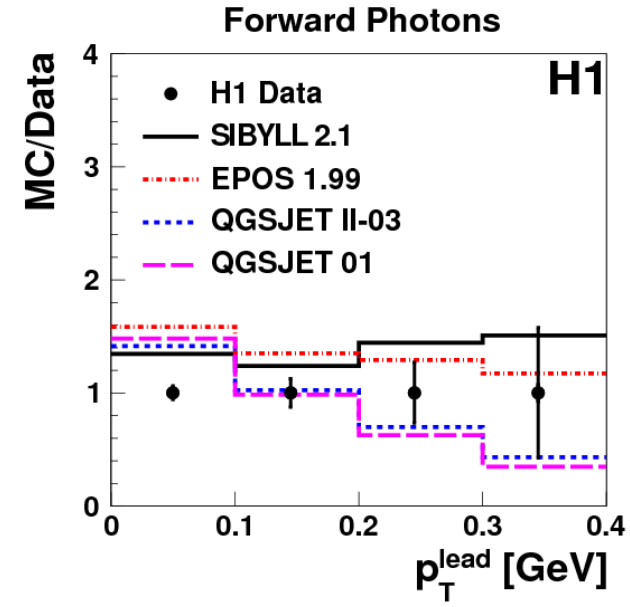
QGSJET models have steeper behavior than the data, close to data in absolute values except at low x_L.

Normalized Forward photon cross sections vs p_T









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Photon rate in all MC the models is significantly higher than in the data.

LEPTO model describe the shape reasonably well.

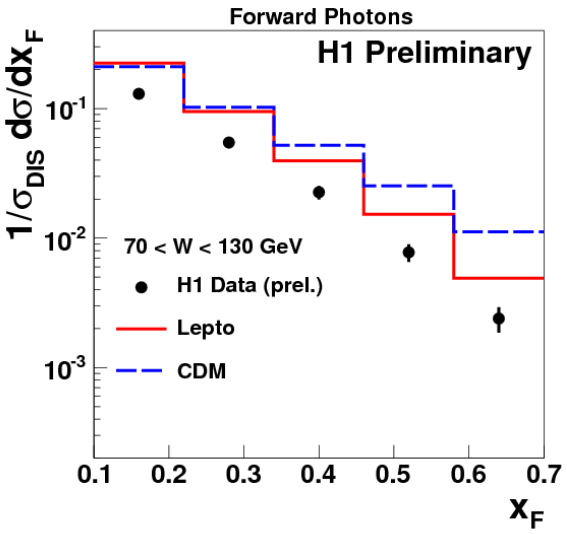
p_T spectrum shape is well described by SIBYLL and EPOS models.

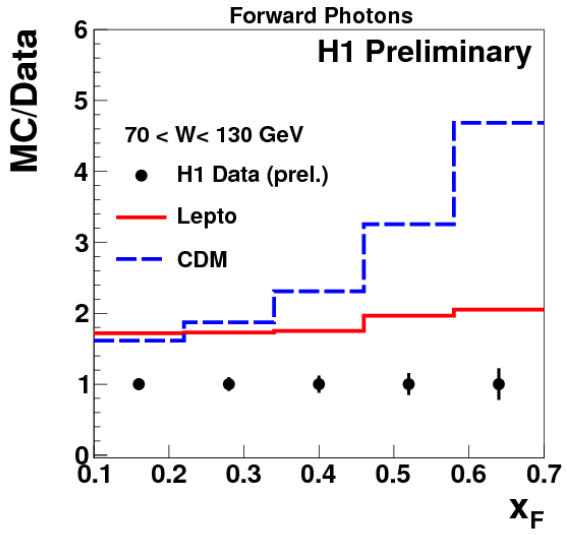
QGSJET also agree with data within uncertainties (except lowest p_T)

$x_F = p^*_{||}/p^*_{||max}$

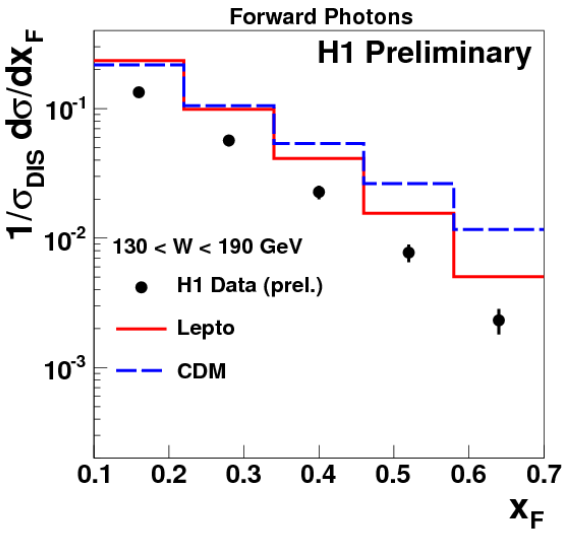
Normalized Forward photon cross sections vs x_F

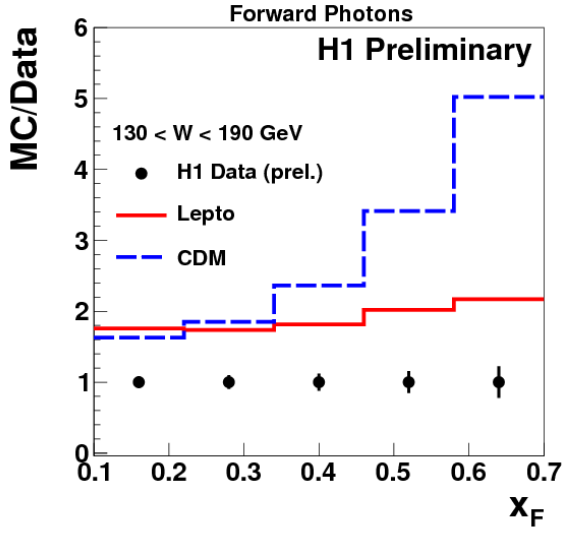
70 < W1 < 130 GeV



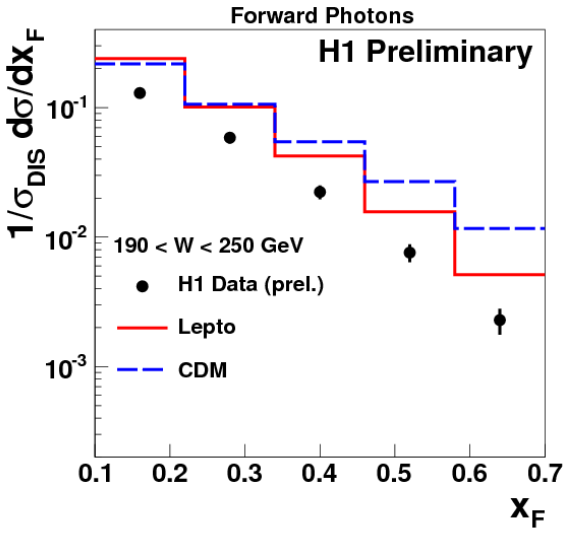


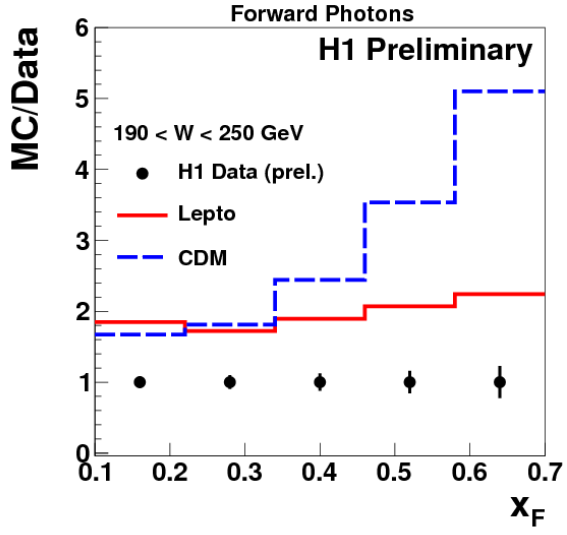
130 < W2 < 190 GeV





190 < W3 < 250 GeV

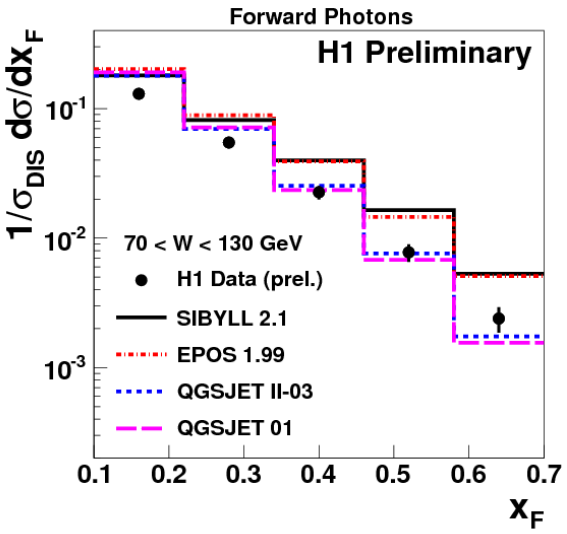


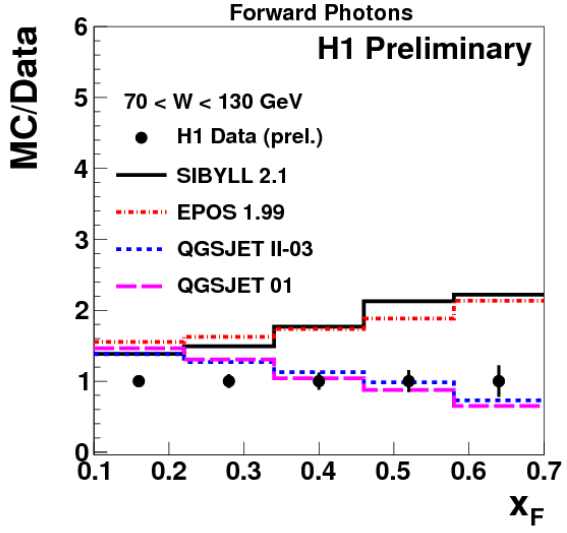


Photon rate in all used MC models is significantly (70%) higher than in the data.
CDM predict much harder x_F spectra,independent of W.

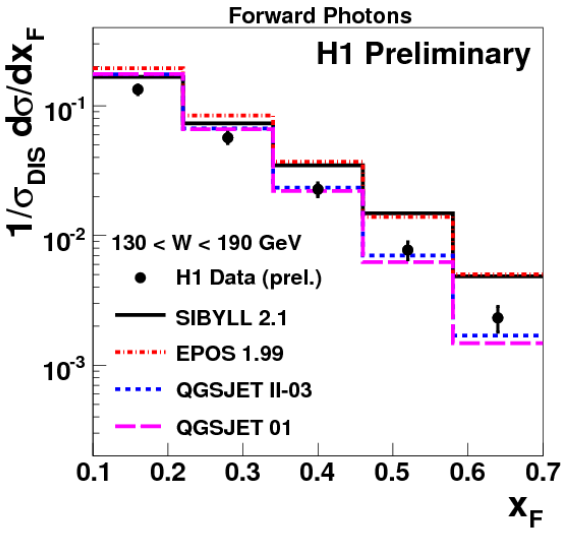
Forward photon cross sections vs X_F (CR)

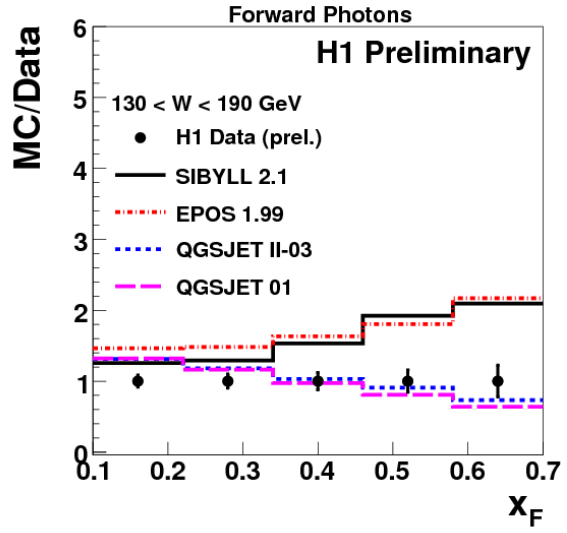
70 < W1 < 130 GeV



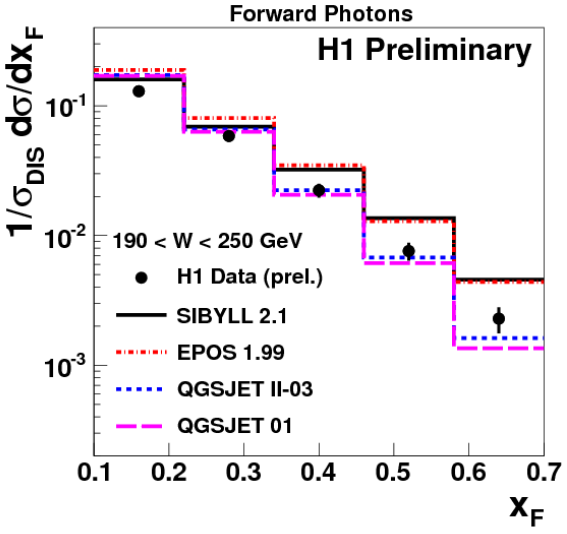


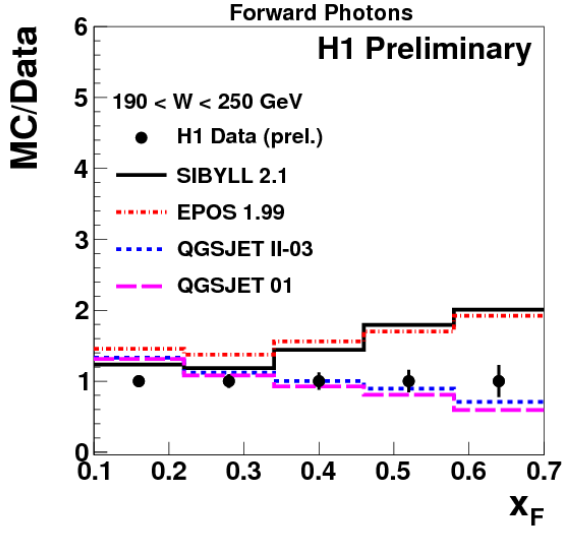
130 < W2 < 190 GeV





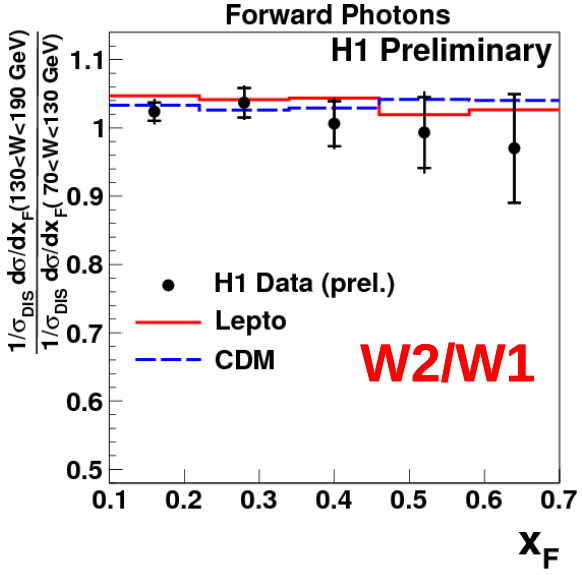
190 < W3 < 250 GeV

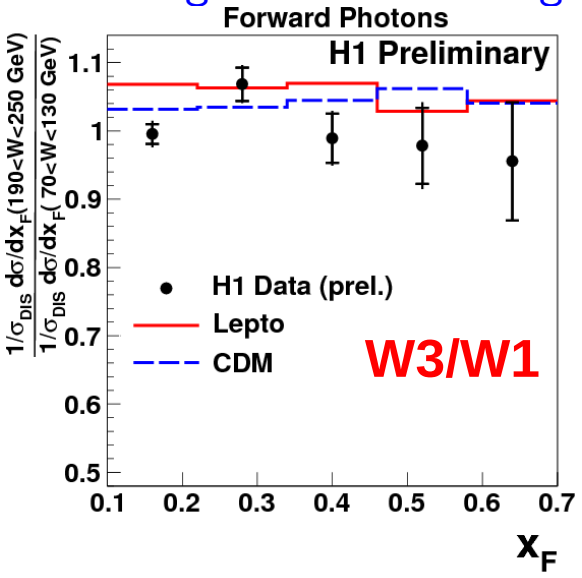


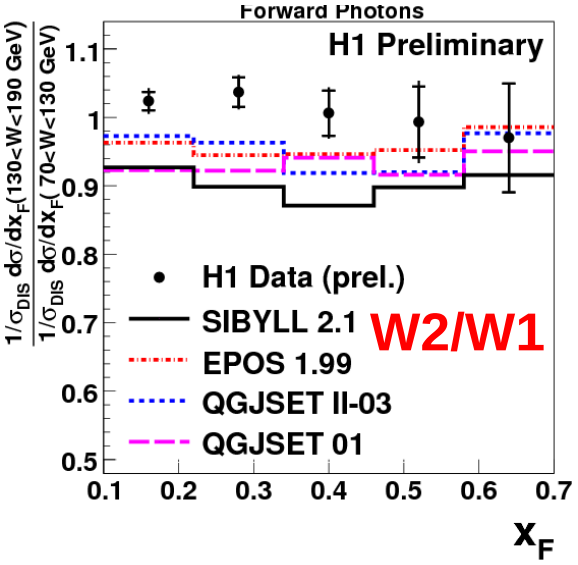


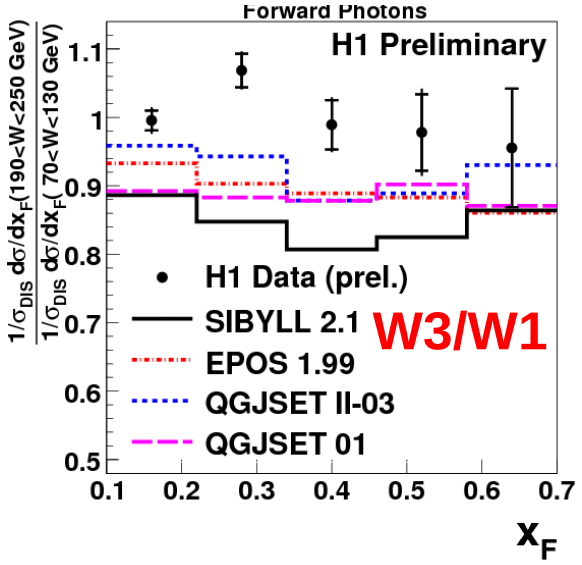
CR models closer to data independent of W.
Best description by QGSJET models.

Ratios of 2-nd and 3-rd W ranges to 1-st W range







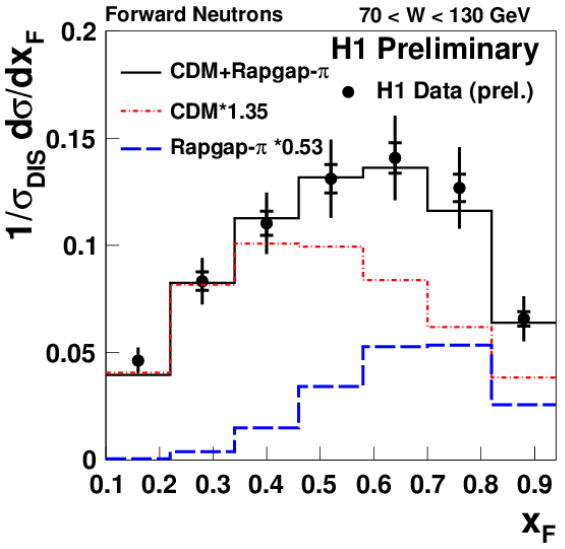


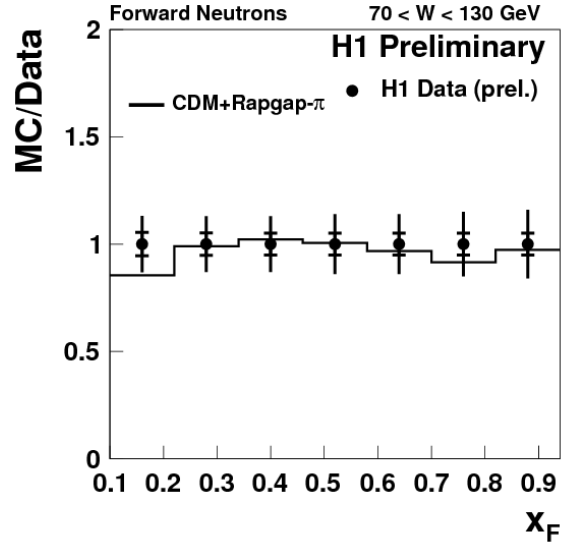
70 < W1 < 130 GeV
130 < W2 < 190 GeV
190 < W3 < 250 GeV

Data consistent with unity within error ==>support Feynman scaling.
CR models show clear deviation from scaling.

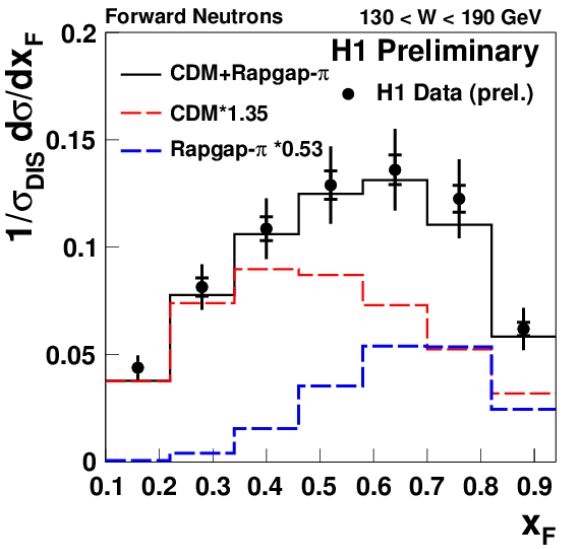
Forward neutrons cross sections vs x_F

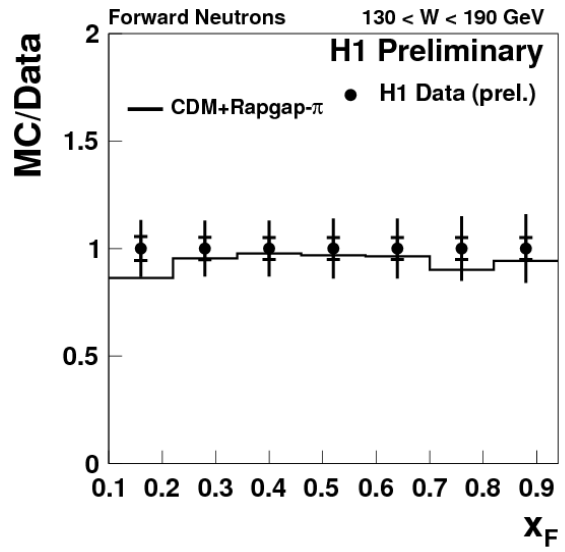
70 < W1 < 130 GeV



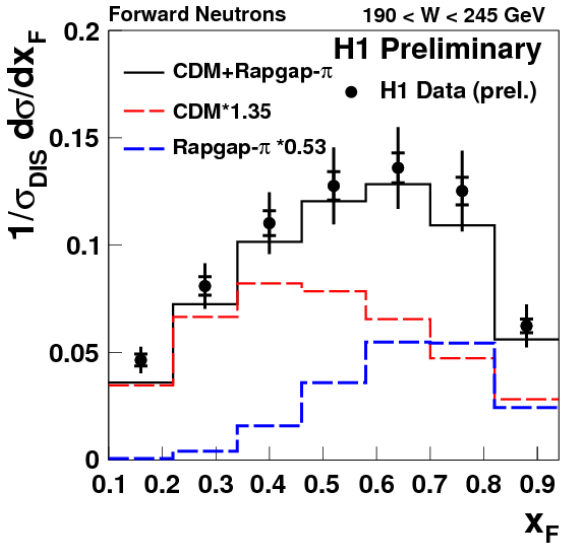


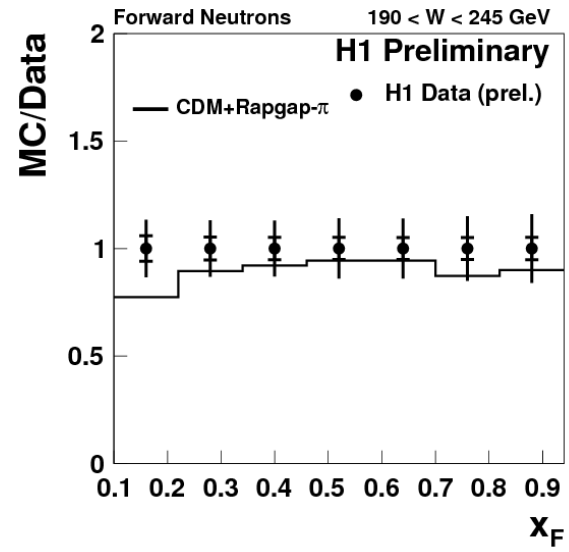
130 < W2 < 190 GeV





190 < W3 < 245 GeV

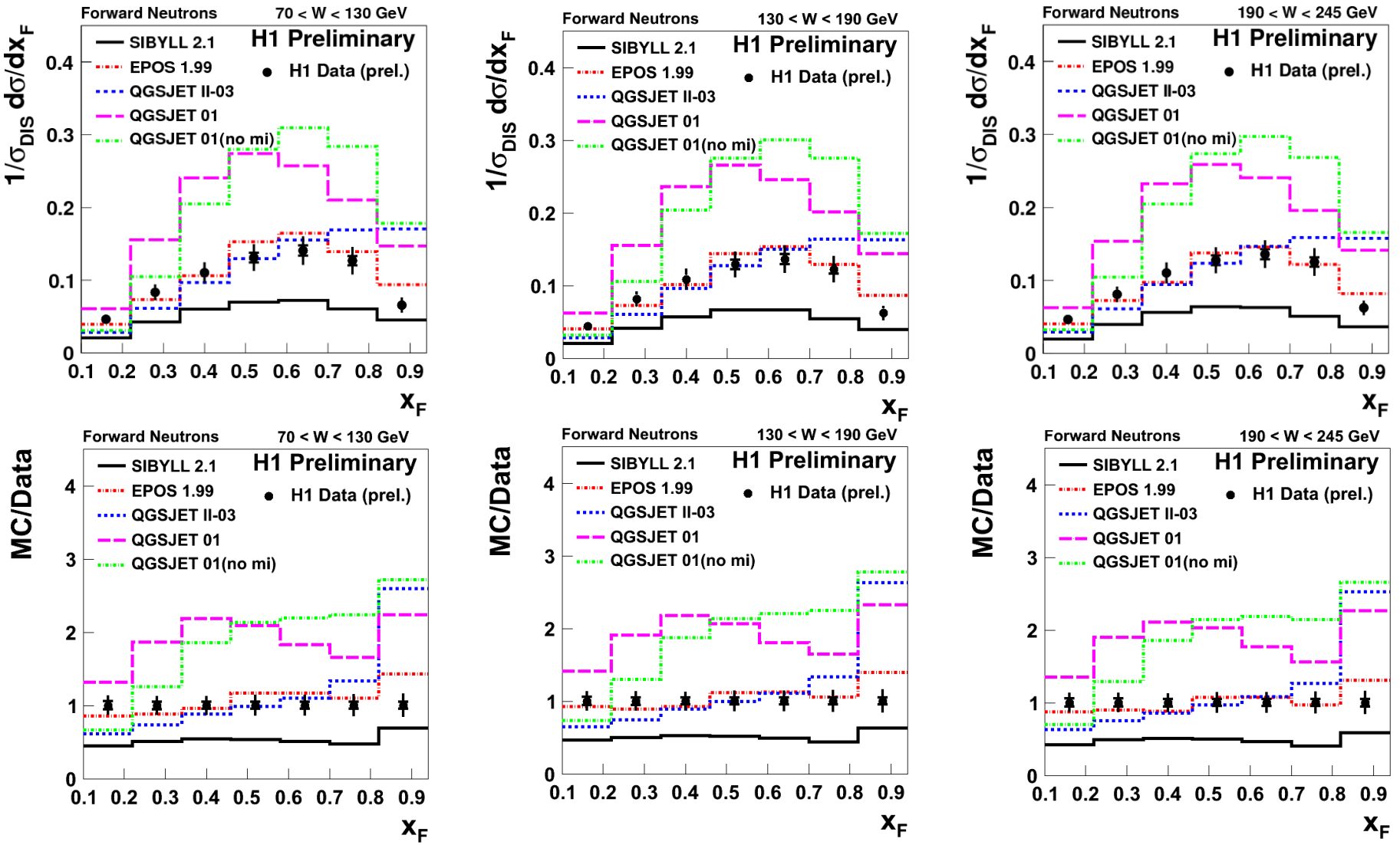




Combination of π-exchange(Rapgap) and 'standard' (CDM) fragmentation models (1.35*CDM+0.53*RAPGAP) describe the data well.

Forward neutrons cross sections vs x_F (CR)

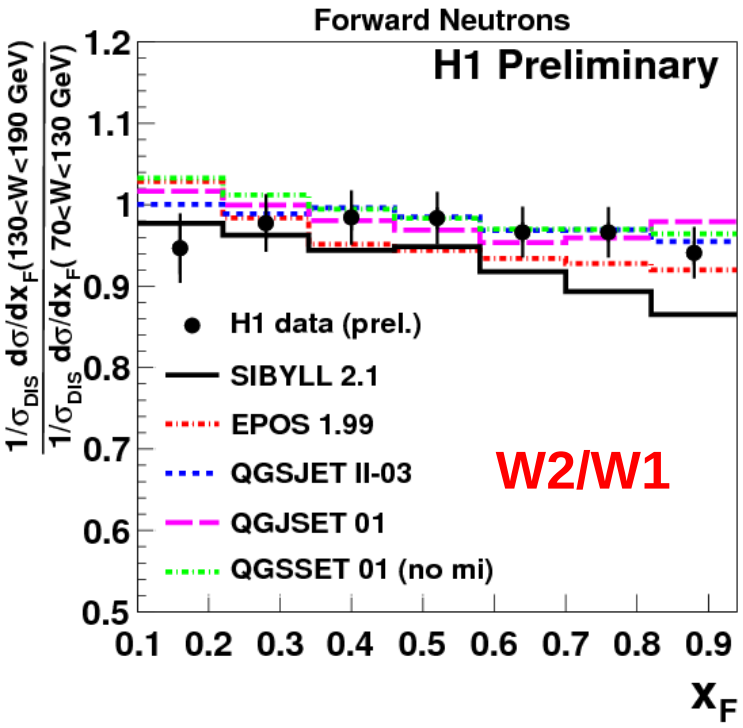
70 < W1 < 130 GeV | **130 < W2 < 190 GeV** | **190 < W3 < 245 GeV**

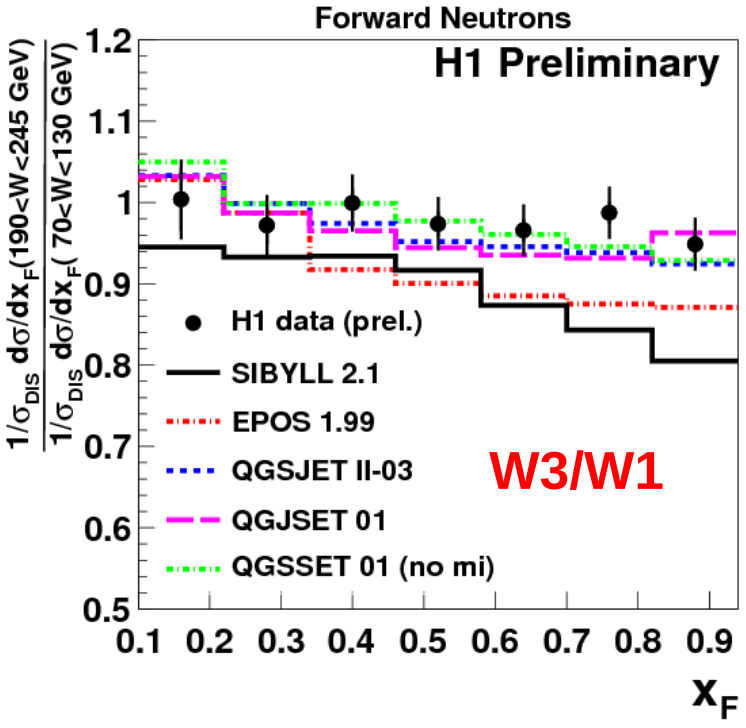


Large spread of models, EPOS gives best description of the data.

Ratios of 2-nd and 3-rd W ranges to 1-st W range

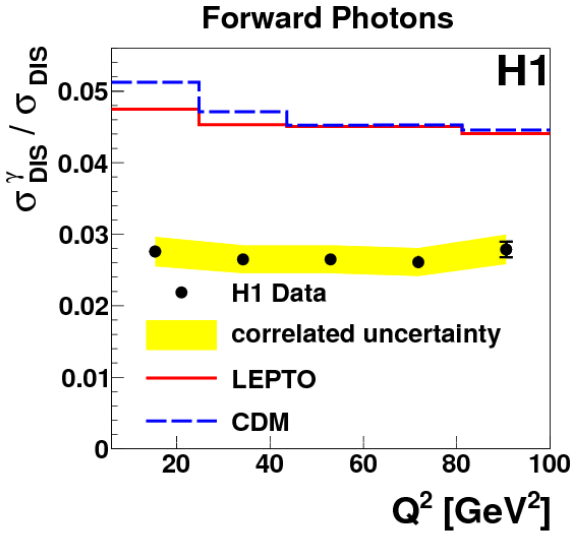
70 < W1 < 130 GeV
130 < W2 < 190 GeV
190 < W3 < 245 GeV

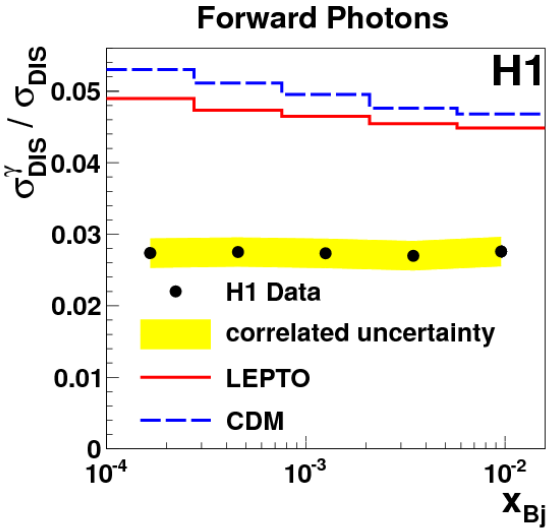


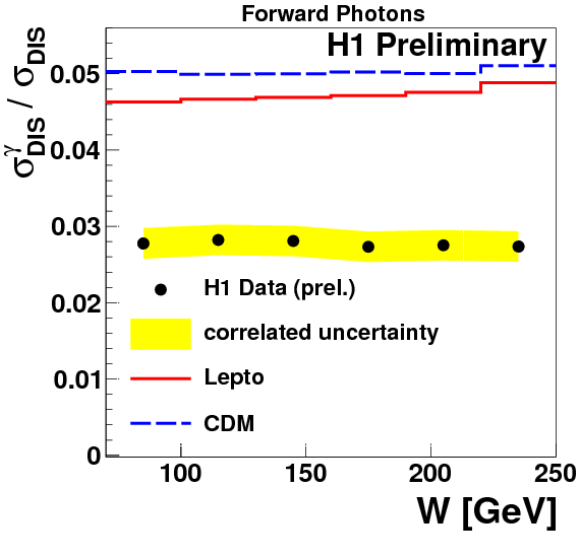


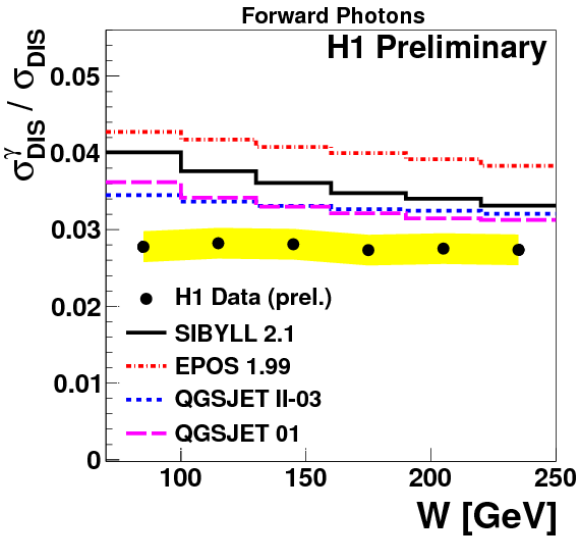
Data ratios are independent of x_F and consistent with unity within errors
Some of CR models show clear deviation from unity

Fraction of DIS events with forward Photons vs Q^2 and X_{Bj}









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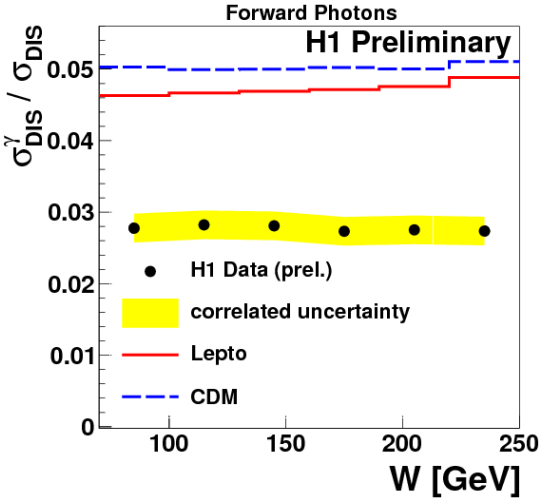
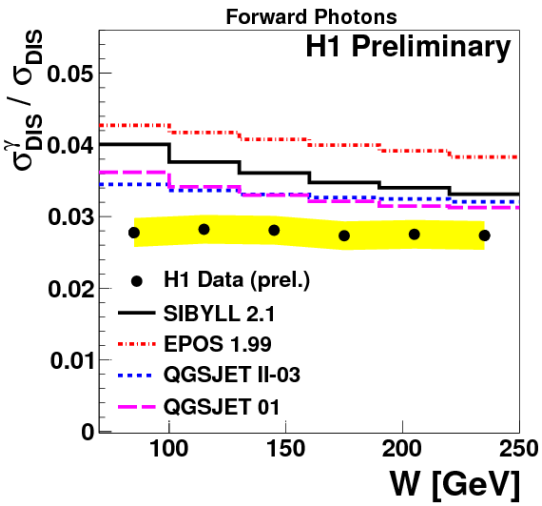
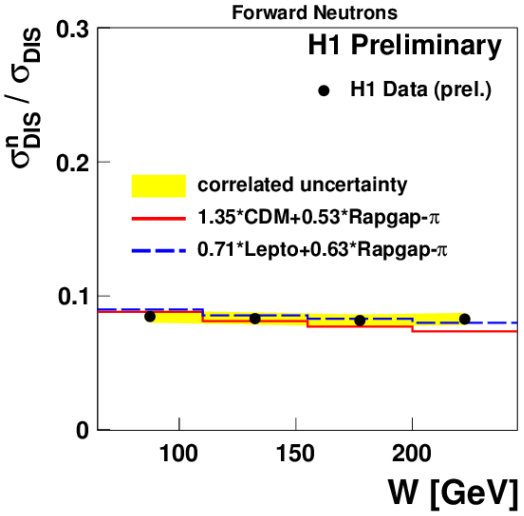
Fraction of DIS events with forward Photons and Neutrons vs γ*p CM energy W

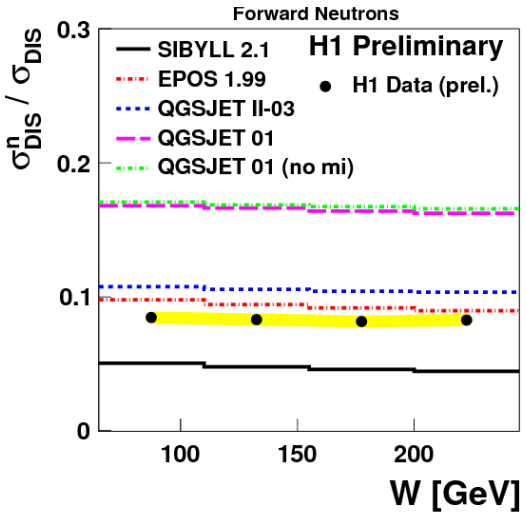
Forward Photons





Forward Neutrons





- Fraction of DIS events with forward photons and neutrons independent of CM energy W
  ==>consistent with limiting fragmentation
- All models predict too high rate of forward photons.
- Large spread of CR models prediction.
- Models indicate W dependencies of photons and neutrons yields

Conclusions

- **Presented measurements of very forward photon and neutrons production in DIS at HERA-H1.**
- **Measurements show sensitivity to proton fragmentation models.**
  ==> Useful input for MC model tuning.

Forward Photons:

- **All models predict significantly higher yield of photons compared to the data.**
- **LEPTO describe the shape of the data.**
- **CDM predicts harder x_F spectra.**
- **CR models are closer to the data in normalisation.**

Forward Neutrons:

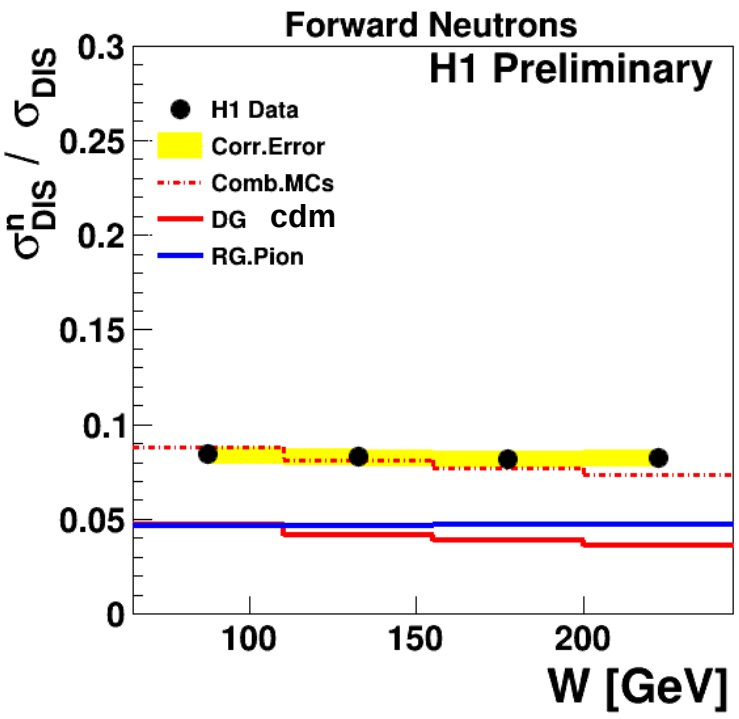
- **No model describes the data well**
- **Combination of standard fragmentation and π-exchange models describes x_F spectra well.**

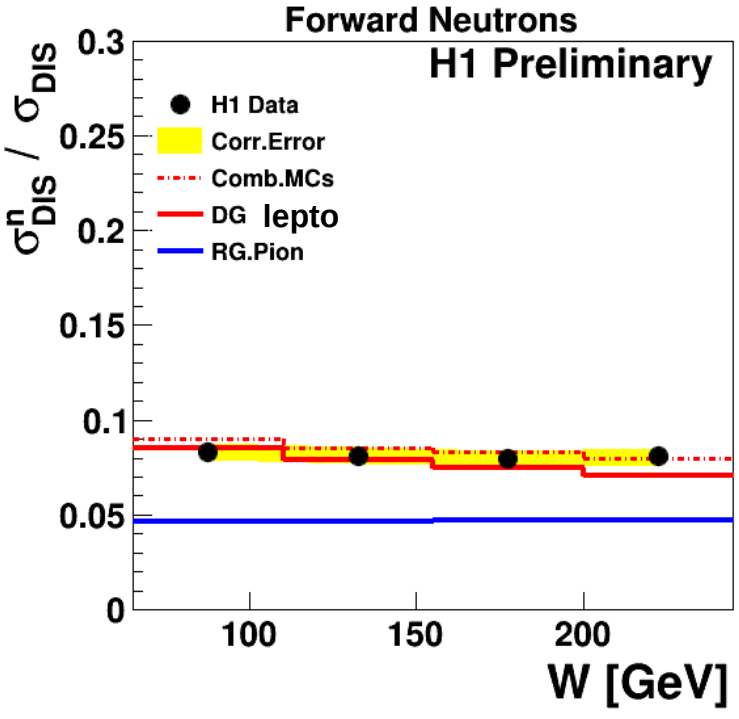
The measurements:

- **Support the Limiting Fragmentation Hypothesis.**
- **Consistent with Feynman Scaling.**

Fraction of DIS events with forward neutrons vs W

Test of limiting fragmentation hypothesis
(Forward particle production insensitive to W).



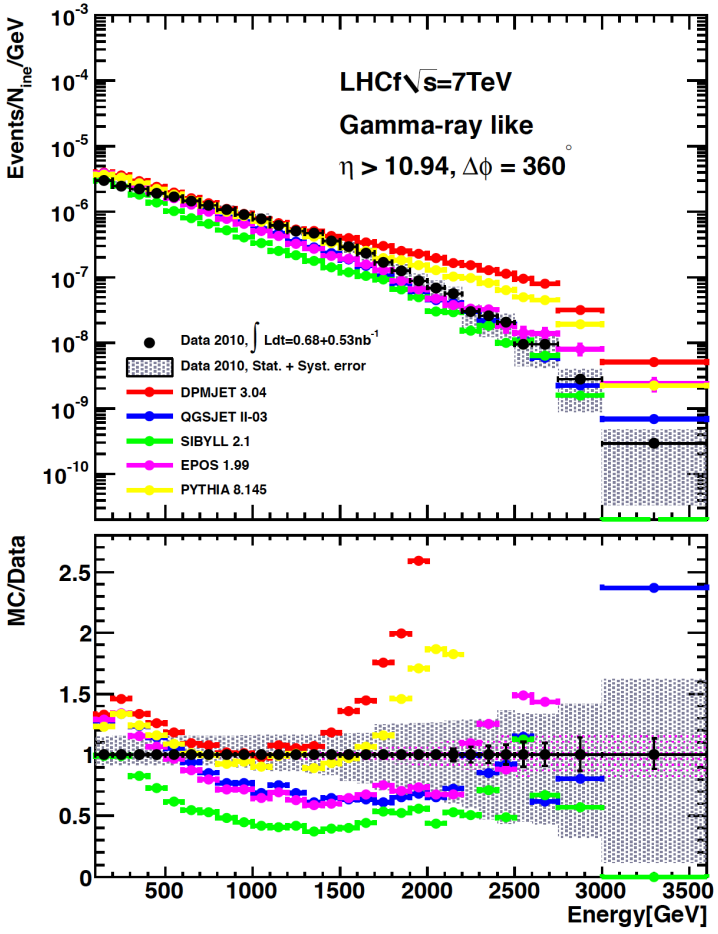


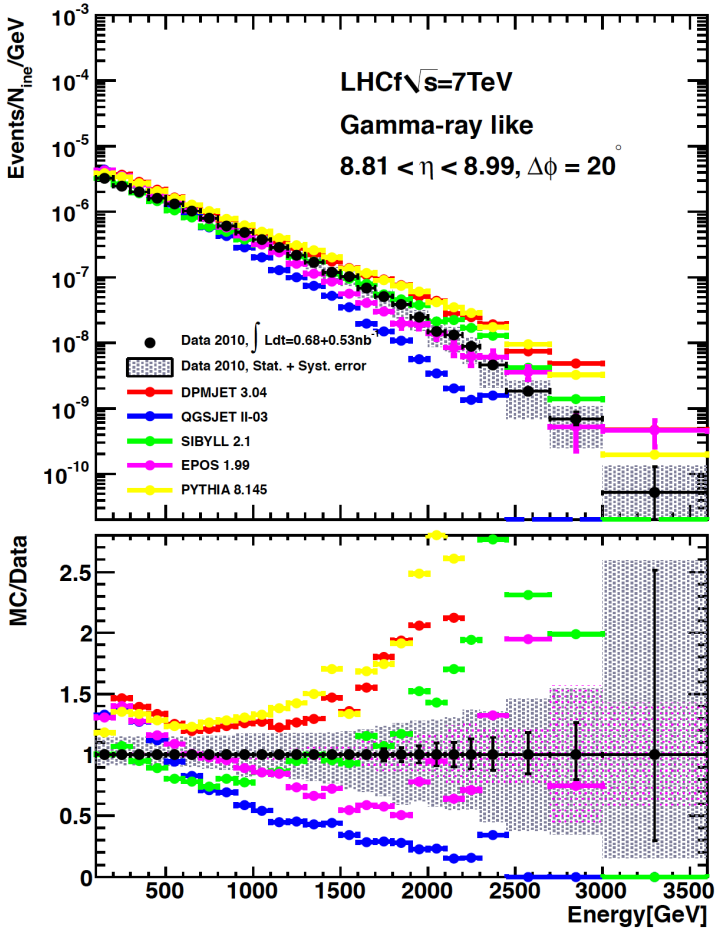
LEPTO closer to data. CDM lower to data by factor 1.6.
RAPGAP indifferent to W.
Comb.MC sits on data but show slope due to CDM and LEPTO.

Data support the hypothesis of limiting fragmentation.

LHCf Inclusive Photons, arXiv:1104.5294

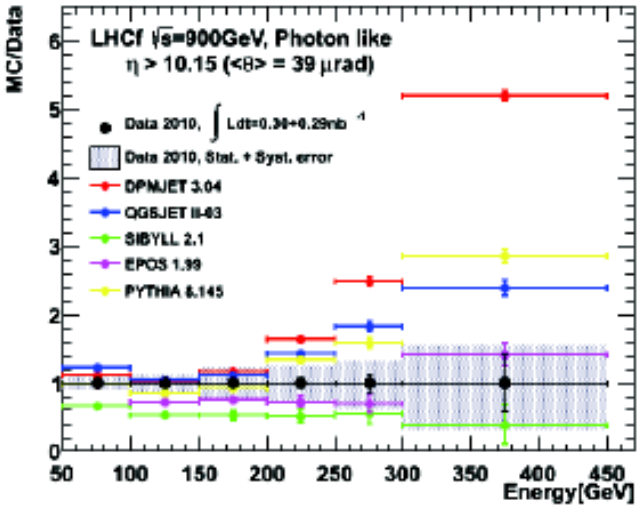
The LHCf experiment has been designed to measure the neutral particle production cross sections at very forward collision angles of LHC pp-collisions.

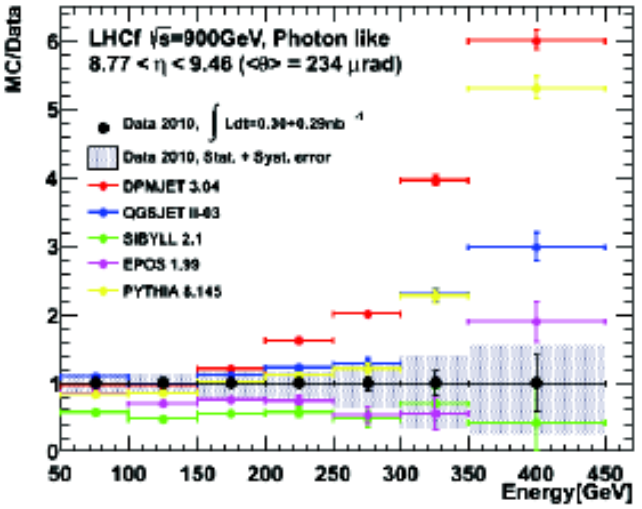




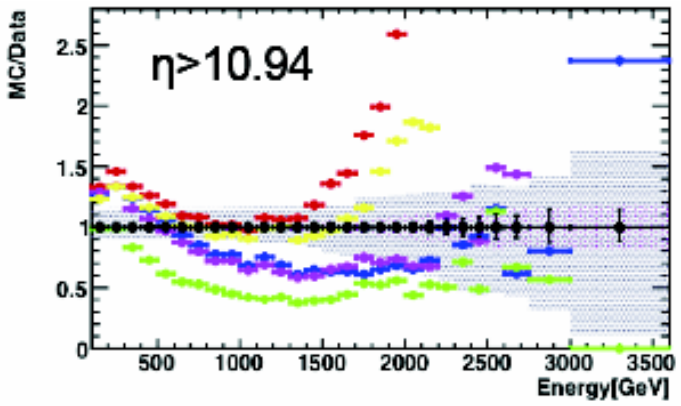
arXiv:1302.6125

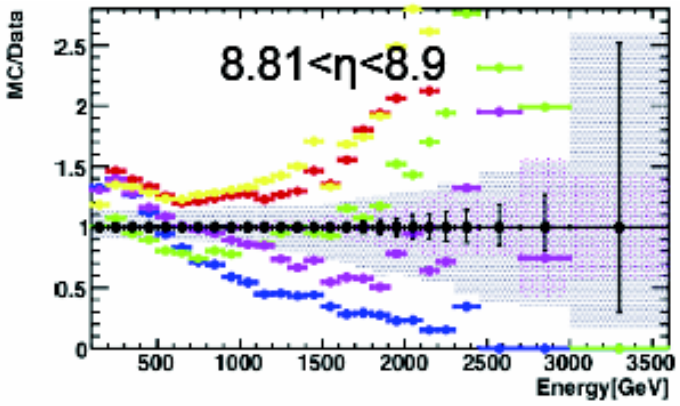
900GeV





7TeV





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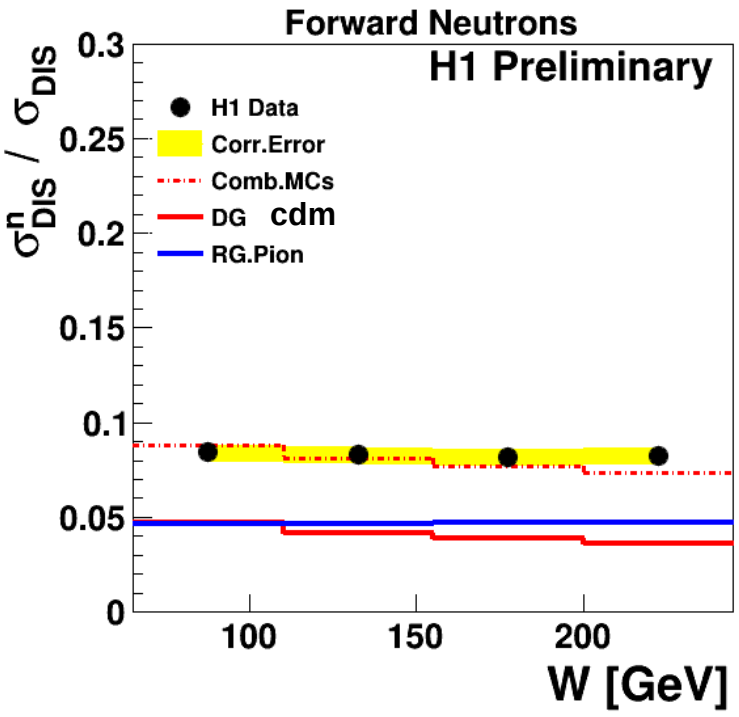

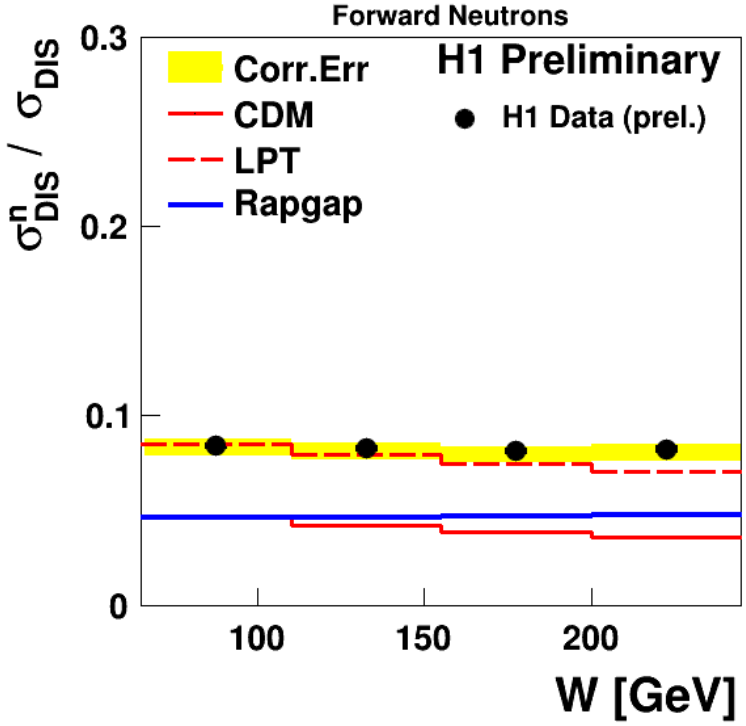

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